ROTATIONAL BANDS IN SUPER-HEAVY NUCLEI WITHIN THE LSD+YF MODEL*

Bożena Nerlo-Pomorska, Krzysztof Pomorski

Institute of Physics, Theoretical Physics Department
Maria Curie-Skłodowska University, Lublin, Poland

J. Bartel

Institute Pluridisciplinaire Hubert Curien, Université de Strasbourg
Strasbourg, France

(Received December 21, 2018)

Rotational energies of heavy and super-heavy nuclei are evaluated in the cranking model which couples the pairing field with the rotational motion. The nuclear ground-state deformation is determined within the macroscopic–microscopic model.

DOI:10.5506/APhysPolBSupp.12.665

1. Introduction

An investigation of heavy and super-heavy nuclei requires a proper model to reproduce masses and rotational energies. We had obtained in the past [1] a very good agreement with experimental data for heavy nuclei using the Yukawa folded (YF) single-particle potential [2] and the Lublin–Strasbourg Drop (LSD) [3]. The Strutinsky shell-correction method [4] and the BCS theory [5] were used to evaluate the shell and pairing energy. The equilibrium deformations of the nuclei were determined with the Modified Funny Hills (MFH) [1] shape parametrisation, and the energies of the rotational states obtained using the cranking model [6]. It was shown in Ref. [7] that a good agreement with the experimental data, especially for larger angular momenta, can only be achieved when a coupling of rotation and the pairing mode is taken into account. We are now going to extend our calculations to rotational states of super-heavy nuclei using a new Fourier-type shape

* Presented at the XXV Nuclear Physics Workshop "Structure and Dynamics of Atomic Nuclei", Kazimierz Dolny, Poland, September 25–30, 2018.

parametrization [8] to describe nuclear deformations more accurately. First results of this project as obtained in a 3-dimensional deformation space are presented below.

2. Theoretical model

In the macroscopic–microscopic method [9], the total energy of a nucleus at a given deformation (def) is the sum of the macroscopic energy and microscopic corrections due to shell and pairing effects

$$E_{\rm tot}({\rm def}) = E_{\rm LSD}({\rm def}) + E_{\rm shell}({\rm def}) + E_{\rm pair}({\rm def})\,. \tag{1}$$

The shell-correction energy is obtained as the difference between the single-particle energy sum and the corresponding Strutinsky averaged result [4], while pairing corrections are determined as the difference between the BCS [5] energy and the single-particle level sum, plus an average pairing energy [10]. Energy landscapes were calculated in Ref. [1] on a two-dimensional grid of Modified Funny Hills [11] shapes with the Lublin–Strasbourg Drop and using Yukawa-folded single-particle levels for the quantal corrections. Rotational states were determined within the cranking model in the ground-state minimum and reproduced the experimental data or served as predictions in the case of heavy and super-heavy nuclei as shown in Fig. 1. We are now going to investigate these and some new even–even super-heavy nuclei using the new Fourier-shape parametrisation [8] in a 3D space including elongation (q_2), octupole (q_3) deformation and neck degrees of freedom (q_4).

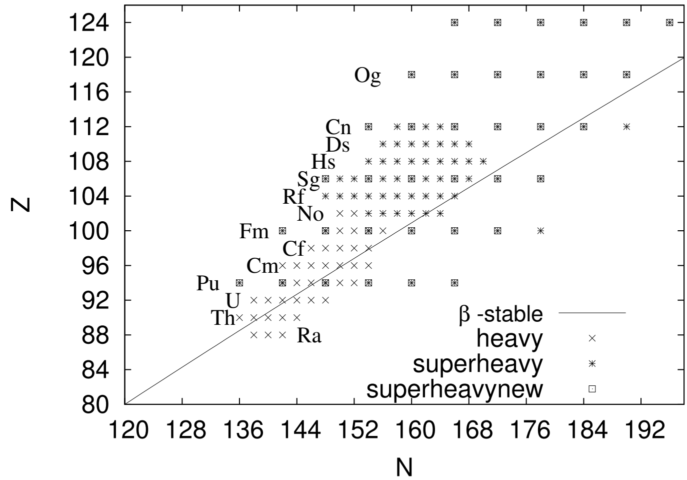

Fig. 1. Nuclei for which the energies of rotational states have been determined in the MFH ($\times$ and $\star$) and Fourier ($\Box$) shape parametrizations. The β-stability line is drawn as a guideline.

3. Results

The calculations were performed for even–even nuclei with charge numbers from $Z = 94$ to $Z = 112$, since nuclei with larger Z are probably not living long enough to perform spectroscopy studies [12]. In Fig. 2, we present the difference of theoretical and experimental [13] masses of nuclei between No and Hs. With the single exception of ^{264}Hs, this deviation never exceeds 0.3 MeV. As an example, the deformation energy sur-

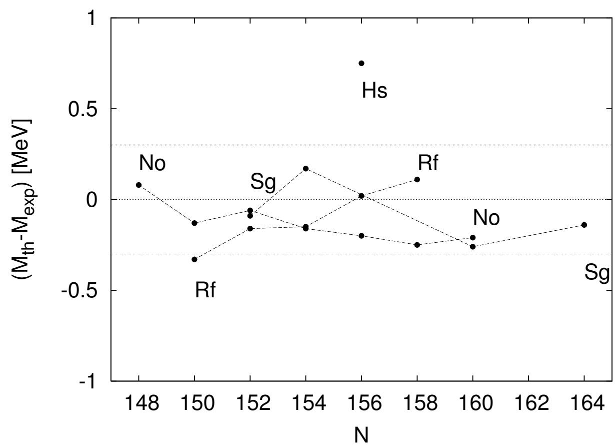

Fig. 2. Difference between theoretical and experimental masses $M_{\rm th} - M_{\rm exp}$ for No up to Hs even–even isotopes as a function of the neutron number N (see Ref. [1]).

face $E_{\rm def} = E_{\rm tot}(q_2, q_3, q_4^{\rm min}) - E_{\rm LSD}^{\rm sph}(0, 0, 0)$ of ^{254}No is presented in Fig. 3 as a function of the deformation parameters q_2 (elongation) and q_3 (left–right asymmetry), with a minimisation with respect to q_4 (neck parameter). One observes two pronounced minima corresponding to the ground

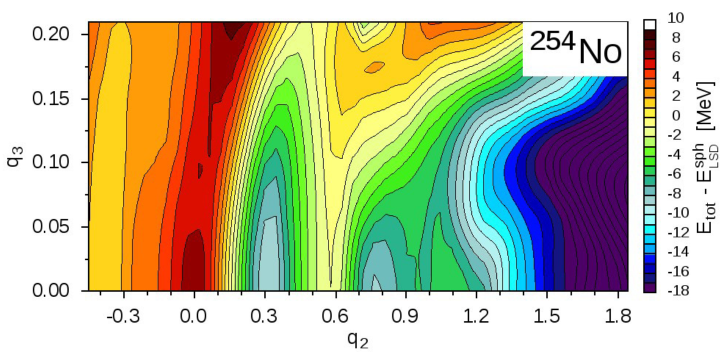

Fig. 3. Deformation energy $E_{\rm def}$ for ^{254}No as a function of elongation q_2 and octupole parameter q_3 minimised with respect to q_4 (neck degree of freedom).

and the fission-isomeric state. In Fig. 4, the deformation energy surface $E_{\rm def} = E_{\rm tot}(0.3, q_3, q_4) - E^{\rm sph}_{\rm LSD}(0,0,0)$ of this nucleus ^{254}No is displayed for the ground state ($q_2 = 0.3$), which turns out to be octupole and hexadecapole symmetric.

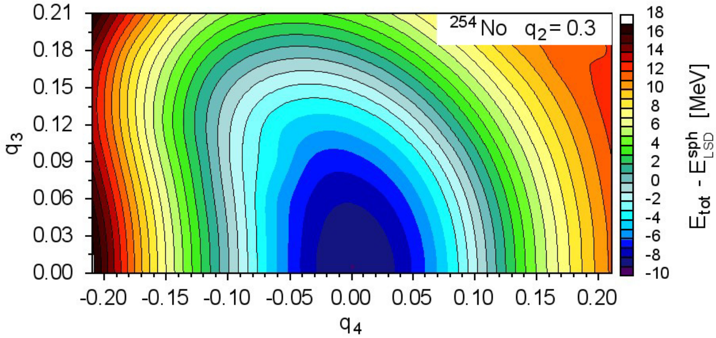

Fig. 4. Deformation energy $E_{\rm def}$ for ^{254}No as a function of q_4 and q_3 in a ground-state elongation $q_2 = 0.3$.

To obtain the rotational energies, $E_L = L(L+1)/2\mathcal{J}$, the moments of inertia $\mathcal{J}$ are calculated microscopically within the cranking model [6] for the ground state using a Yukawa-folded single-particle potential. Rotational energies of No isotopes for $L/\hbar = 2,4,6,8,10,12$ are compared with the experimental data [14] in Fig. 5. As seen from the figure, one obtains an almost perfect agreement when a pairing strengths of $G\,N_q^{2/3} = 0.32\,\hbar\omega_0$ with $N_q = N, Z$ and $\hbar\omega_0 = 41\,{\rm MeV}/A^{1/3}$ when the pairing window of $2\sqrt{15N_q}$ single-particle levels [15] is used. Figure 6 gives a prediction of the E_{2+} ro-

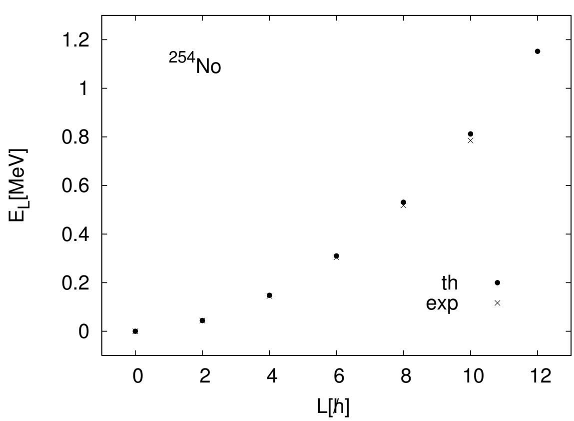

Fig. 5. Theoretical and experimental rotational energies E for ^{254}No as functions of the angular momentum L.

tational energies for even–even nuclei between No and Cn. In a forthcoming extension of the present work, we are going to predict the rotational energies of heavy and super-heavy nuclei with $92 \leq Z \leq 126$ and $132 \leq N \leq 200$ within LSD+YF model using the Fourier shape parametrisation [8, 18] in a 4D deformation space.

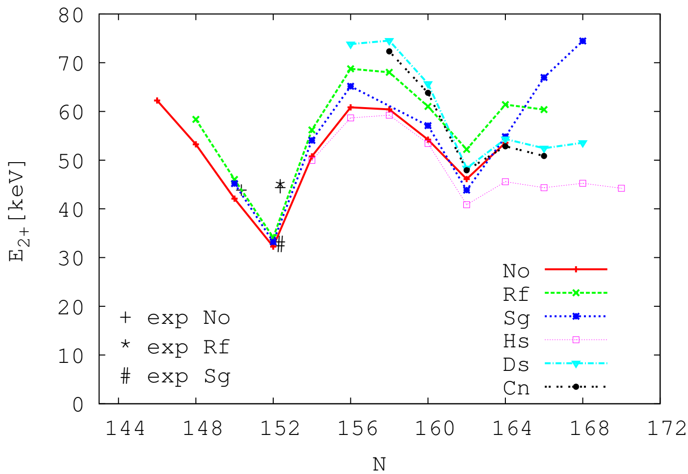

Fig. 6. Rotational energies E_{2+} for even–even isotopes of nuclei between No and Cn in their ground state as functions of the neutron number N [16, 17].

This work has been partly supported by the Polish–French COPIN-IN2P3 collaboration agreement under project number 08-131 and by the National Science Centre, Poland (NCN), grant No. 2016/21/B/ST2/01227.

REFERENCES

[1] A. Dobrowolski, B. Nerlo-Pomorska, K. Pomorski, *Acta Phys. Pol. B* **42**, 105 (2011).

[2] K.T.R. Davies, J.R. Nix, *Phys. Rev. C* **14**, 1977 (1976).

[3] K. Pomorski, J. Dudek, *Phys. Rev. C* **67**, 044316 (2003).

[4] V.M. Strutinsky, *Nucl. Phys. A* **95**, 420 (1967).

[5] J. Bardeen, L.N. Cooper, J.R. Schrieffer, *Phys. Rev.* **108**, 1175 (1957).

[6] S.G. Nilsson, O. Prior, *Mat. Fys. Medd. Dan. Vid. Selsk* **32**, 16 (1961).

[7] B. Nerlo-Pomorska, K. Pomorski, J. Bartel, *Phys. Rev. C* **84**, 044310 (2011).

[8] C. Schmitt, K. Pomorski, B. Nerlo-Pomorska, J. Bartel, *Phys. Rev. C* **95**, 034612 (2017).

[9] W.D. Myers, W.J. Świątecki, *Nucl. Phys.* **81**, 1 (1966); *Ark. Phys.* **36**, 343 (1967).

[10] B. Nerlo-Pomorska, K. Pomorski, *Int. J. Mod. Phys. E* **16**, 328 (2007).

[11] K. Pomorski, J. Bartel, *Int. J. Mod. Phys. E* **15**, 417 (2006).

[12] A. Sobiczewski, K. Pomorski, *Prog. Part. Nucl. Phys.* **58**, 292 (2007).

[13] M.S. Antony, *Nuclide Chart, Strasbourg 2002*, Impressions Francois, Hagenau 2002.

[14] http://www.nndc.bnl.gov/nudat2

[15] S.G. Nilsson *et al.*, *Nucl. Phys. A* **131**, 1 (1969).

[16] P.T. Greenlees *et al.*, *Phys. Rev. Lett.* **109**, 012501 (2012).

[17] B. Nerlo-Pomorska, K. Pomorski, J. Bartel, *Phys. Rev. C* **81**, 044310 (2011).

[18] B. Nerlo-Pomorska, K. Pomorski, J. Bartel, C. Schmitt, *Acta Phys. Pol. B* **48**, 451 (2017).